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SHAPING THE FUTURE OF AEROSPACE

Advances seen in nuclear propulsion for human missions to Mars

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The **Nuclear and Future Flight Propulsion Technical Committee** works to advance the implementation and design of nonchemical, high-energy propulsion systems other than electric thruster systems.

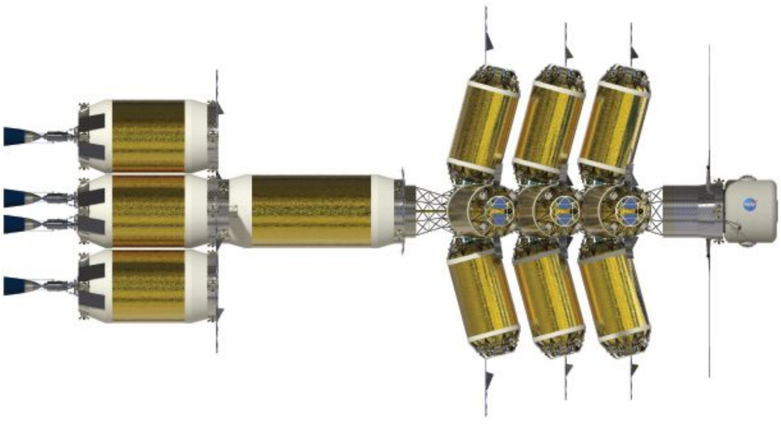
Significant progress toward deciding the **best propulsion method for a crewed mission to Mars** occurred this year when researchers from Aerojet Rocketdyne unveiled **options for Mars opposition class (very high energy) missions** that would utilize low enriched uranium fuel in nuclear thermal propulsion engines.

Aerojet Rocketdyne has been working with NASA and industry partners since 2016 to "increase the feasibility" of such LEU designs, the authors note in the paper "Mars Opposition Missions Using Nuclear Thermal Propulsion" presented at the virtual AIAA Propulsion and Energy Forum.

NTP work has often focused on highly enriched uranium fuels for Mars conjunction class (or lower energy delta-velocity) missions to provide flight times of 900 days, 600 of them in Mars orbit. An opposition-class mission would have a duration of less than two years but demand two to three times the delta-V.

For such LEU missions, researchers investigated main engine specific impulse, or Isp, the appropriate number of engines and the Earth orbital location of the Mars transfer vehicle. By using drop tanks, a form of rocket staging, the performance of the overall vehicle significantly improved. Essentially, empty propellant tankage would be dropped off as the hydrogen propellants are expended. Both Space Launch System and commercial launch vehicles were included in the team's efforts.

▼ **Hydrogen fuel stored** in 12 drop tanks on the right side of this assembly would be accelerated through the nuclear thermal engines on the left side, safely propelling a crew toward Mars in their Deep Space Habitat labeled with the NASA logo.
NASA



Several NTP designs showed significant LEU benefits for both cargo and crewed Mars missions. To get the vast amount of required hydrogen propellant into space, commercial vehicles and NASA Space Launch System rockets would be launched to deliver up to 12 drop tanks of hydrogen fuel to the awaiting crew or cargo spacecraft. The hydrogen fuel would be passed through the nuclear reactors, one per engine. Once a drop tank is emptied, it would be discarded at a predetermined staging location. Many assembly locations and architectures showed promising assembly options for human Mars missions.

Also at the August AIAA event, Greg Sullivan, the former deputy manager of the **U.S. Space Nuclear Thermal Propulsion program** (originally called **Timberwind**), briefed attendees about the program's achievements in the 1980s and '90s. In the most important test of the SNTP engine technology, engineers pumped hydrogen fuel into a reactor filled with sand-sized zirconium-carbide coated fuel particles. They achieved a temperature of 3,000 K, meaning the Particle-Bed Reactor could have yielded double the specific impulse, or fuel efficiency, of a chemical rocket engine and also more thrust. The program was transferred from the Strategic Defense Initiative Organization to the Air Force and terminated before a full engine was built. If the engine had operated, it would have run for two minutes, meaning it could not be directly applicable to a Mars mission requiring hours of operation.

Turning to other technologies, utilizing lasers to deliver energy over vast distances has the potential to realize rapid transit missions within the solar system, interstellar precursor missions and true interstellar missions to other solar systems. In August, McGill University in Montreal proposed the use of **directed light energy onto a low areal density reflective foil, or lightsail**. The reflected beam would be capable of accelerating spacecraft to speeds on the order of a quarter of the speed of light. To achieve such great velocities in the near-field of the laser array necessitates great accelerations and thus large dynamic loads being applied to the lightsail. In the case of an ideally smooth sail, the impinging light would undergo normal specular reflection, thereby ensuring the sail's shape and directional stability, but no material is ever perfectly flat on all scales. Because of the inevitable occurrence of nonuniform loading generated by surface irregularities, it remains uncertain whether a lightsail would retain its shape and not collapse or wrinkle when experiencing the large photon pressures that would be involved in laser-driven interstellar flight. Lightweight onboard support structures are an option to assure the lightsail's success. ★